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Acoustic-resonance method for control of the location of hidden hollow objects

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Abstract. There are quite a number of methods for monitoring the location of buried pipelines: radio wave method, radiation method, acoustic location, resonant-acoustic profiling, infrared thermography, electromagnetic method.
However, these methods have several disadvantages: they are not applicable to pipelines of non-metallic materials, and also have a weak selectivity in controlling the location of buried pipelines when many different communications pass in close proximity to the object under control.
In this work, an improved acoustic-resonance method for controlling the location of hidden hollow objects has been developed and implemented as an information-measuring complex consisting of devices for exciting and receiving forced vibrations. The algorithmic and software-technical support of the processes of controlling the information-measuring complex and processing of vibroacoustic signals in the LabVIEW environment has been developed and created.

1. Improved acoustic resonance method of monitoring the location of the hidden hollow objects made of different materials

Known is a comprehensive method for detecting non-metallic pipelines (polymer-reinforced pipes) and damages on them according to the invention RU No. 2328020, IPCG01V3/08, 20.04.2007, which consists in generating sound vibrations in the pipeline that cause mechanical vibrations of the metal pipe armature in a magnetic field Of the Earth. The electric E and magnetic H components of the emerging electromagnetic radiation, the ground temperature and the noise level emitted by the medium transported through the pipe are measured.

The disadvantage of this method is the difficulty in determining the location of pipelines, due to the presence of a number of monitored parameters, as well as the inability to search for metal pipelines.

The object of the present invention is to provide a simple method that provides high reliability and selectivity in determining the location of both non-metallic and metal pipelines.

The improved acoustic resonance method is described in patent for invention No. 2482515 [14] and consists in the generation of resonance sound waves in the cavity of the desired object, while the delineation of this object is accomplished by moving the sensing element (microphone or piezoelectric sensor) above the search zone.

Figure 2.1 shows a device that implements the proposed method [14-18, 20-24].

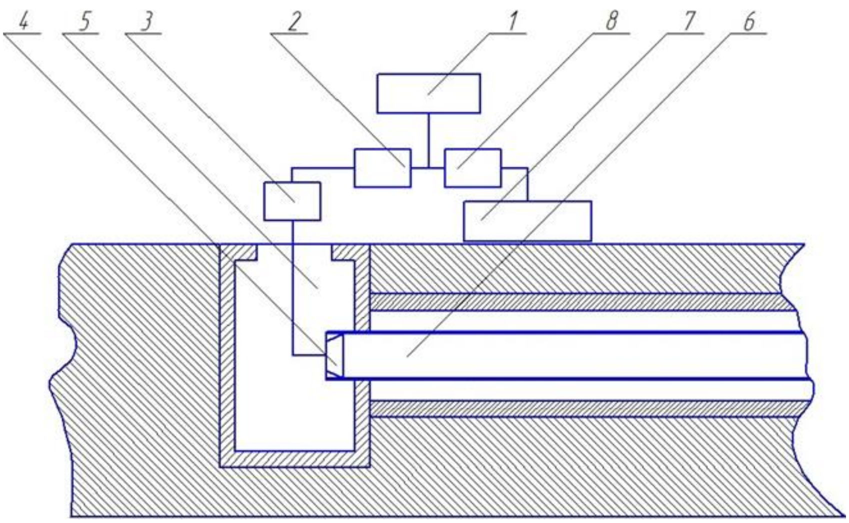


Figure 1. The device that implements proposed method of determining the location of the pipeline (1 – personal computer; 2 – digital-to-analog converter (DAC); 3 – signal amplifier; 4 – dynamic emitter; 5 – well; 6 – pipeline; 7 – sensitive element; 8 – analog-to-digital converter (ADC)).

Monitoring of the location of hidden hollow objects in the following sequence.

The pipeline 6 is released (devastated) from the transported medium. In the well 5, shut-off and control valves connected to the pipeline 6 are removed, and the dynamic emitter 4 is installed in its place, which generates sound waves in the pipeline 6. The sensitive element 7 is installed above the beginning of the pipeline 6.

Under the control of a personal computer (PC) 1, the generated resonant frequency of the pipeline 6 is scanned.

Using a digital-to-analog converter (DAC) 2, the output signal of the PC 1 is converted to analog form, and the amplification of the signal to the dynamic emitter 4, is carried out by the amplifier 3. After registering the resonant frequency of the pipeline 6, the sensitive element 7 is moved above the ground in the direction of preserving the maximum amplitude of the ground oscillations at a given frequency by the gradient search method. The signal is registered by a personal computer 1 by an analog-to-digital converter (ADC) 8. To increase the reliability of determining the location of the pipeline, the search is repeated at other resonant frequencies.

The proposed method allows to simplify the control of the location of hidden hollow objects due to the fact that the resonant frequency of the desired object is excited, and the selectivity of the control increases. The method also provides high accuracy of monitoring the location of buried non-metallic and metal pipelines [14-18, 20-24].

2. Device for monitoring the location of hidden hollow objects made of various materials

The method is implemented in a device for monitoring the location of buried pipelines made of various materials [1-24] for utility model patents No. 120784, No. 120785 [15-16], the principle of which consists in recording sensitive elements of sound signals from a leak or impulse waves, which are created by an additional generator connected to the pipeline.

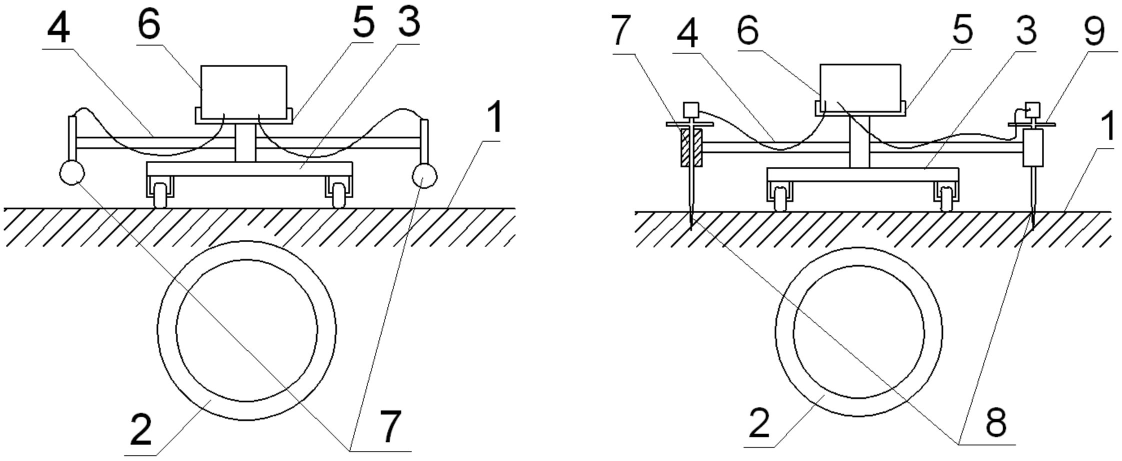
Device for monitoring the location of hidden hollow objects works as follows.

The device is installed above the intended location of the pipeline.

To determine the location of the pipeline, a pulse wave generator is additionally connected to it.

Using telescopic measuring rods 4, the distance between the sensing elements is adjusted, which is especially important when scanning pipelines of various diameters. For convenience of scanning adjustment is made so that the microphones 7 are located at the same distance from the axis of the carriage 3.

Due to the fact that the microphones are located at a certain distance from each other, the level of the sound signal in each of them will be different. To determine the axis of the pipeline 2 buried in the ground 1 or the source of the leak, the carriage 3 is moved in the direction of increasing signals in both microphones. In this case, the difference in signal levels in both microphones will decrease and reach a minimum when the axis of the carriage 3 is above the axis of the pipe 2 or the source of the leak.



1 – ground surface;
2 – pipeline;
3 – carriage;
4 – telescopic measuring rod;
5 – cradle;
6 – acoustic signal difference calculator;
7 – microphone.

1 – ground surface;
2 – pipeline;
3 – carriage;
4 – telescopic measuring rod;
5 – cradle;
6 – acoustic signal difference calculator;
7 – fixing ring;
8 – pin with piezoelectric sensor;
9 – handle.

Figure 2. Device for monitoring the location of hidden hollow objects.

Thus, this solution makes it possible to simplify the process of monitoring the location of buried pipelines and leaks, reducing the number of scanning operations, and also ensuring reliable detection of pipelines of various diameters and materials [14-24].

To test the proposed method of monitoring the location, an information and measurement complex was created in the work, which consists of an experimental installation and software.

3. Development and creation of information-measuring complex

3.1 Development and manufacture of an experimental setup in the laboratory/

In order to conduct experiments at the department «Industrial heat power engineering and heat supply systems» of KSPEU, a laboratory installation was developed.

The structural diagram of a laboratory installation for monitoring the location of buried pipelines is shown in Fig. 3.1 [1-24] and includes excitation device (acoustic emitter), piezoelectric sensors, ADC-DAC and personal computer. The acoustic radiator is supplied with a harmonic signal of the oscillating frequency in the range from 100 to 4000 Hz.

Using the digital-to-analog converter (DAC) 2, the PC output signal is converted to an analog form. For reception of a vibroacoustic signal in system piezoelectric sensors of mark KD-35 are applied. The received signal by a piezoelectric sensor is converted into a digital code from an analog signal to an

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ADC and analyzed in a personal computer [1-22]. The appearance of the laboratory installation is shown in Fig. 3.2 and Fig. 3.3

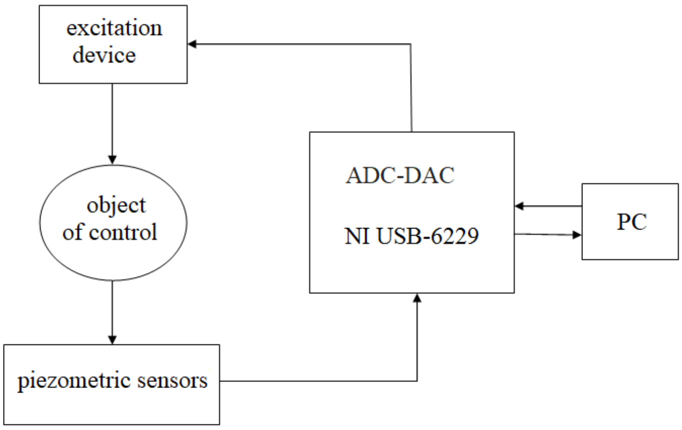

Figure 3.1. Block diagram of the laboratory installation.

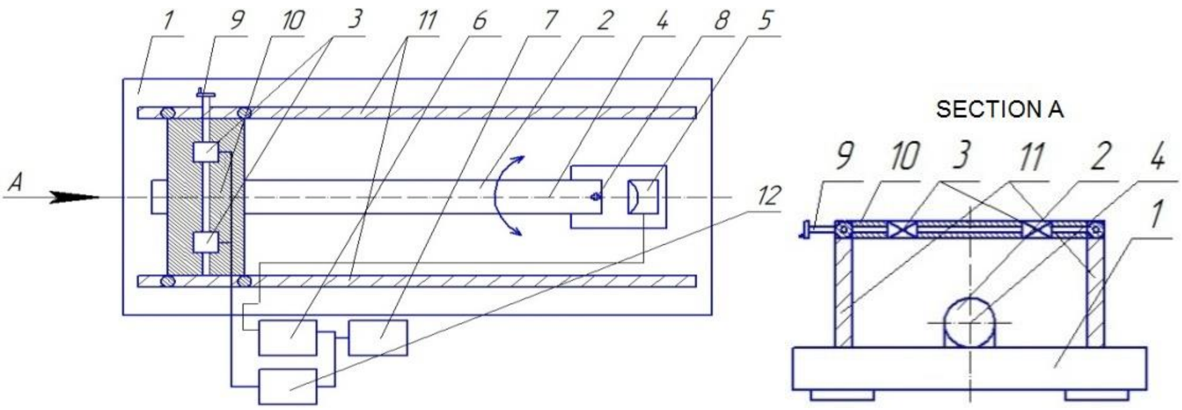

Figure 3.2. Laboratory installation: 1 – base; 2 –pipeline; 3 – piezoelectric sensors; 4 – longitudinal axis; 5 – acoustic emitter (dynamic); 6 – DAC; 7 –PC; 8 – swivel mount of the pipeline to the base; 9 – device for moving piezoelectric sensors; 10 – movable carriage; 11 – guides of the movable carriage; 12 – ADC.

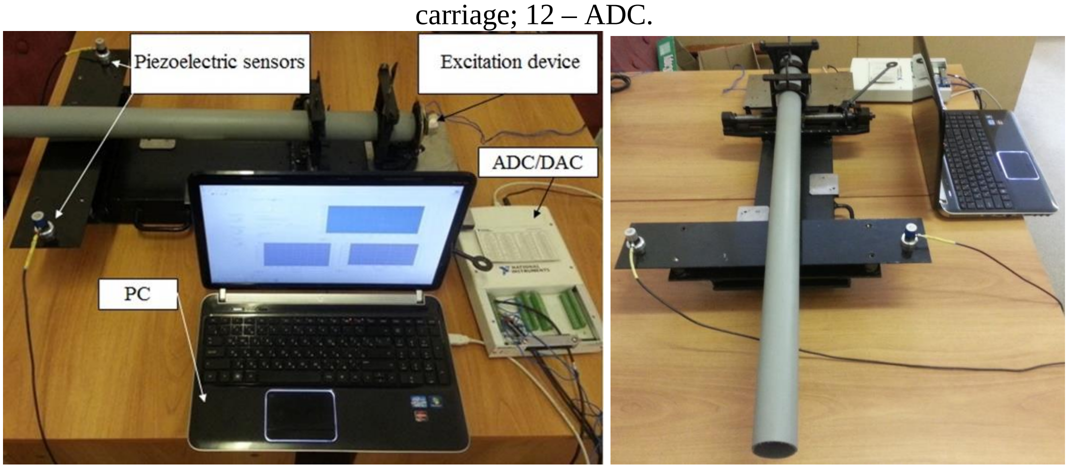

Figure 3.3. Photo of the laboratory installation.

3.2 Development and creation of software for the work of the information-measuring complex.

In the graphical application development environment "LabVIEW" software was created "Software complex for monitoring the location of hidden hollow objects at their resonance frequency" (see the state program No. 2013610546, No. 2012661393) [1-24]
The program "Software complex for monitoring the location of hidden hollow objects at their resonant frequency" is designed to control the location of buried pipelines of various diameters and materials at their resonance frequency.

The program provides the following functions:

• selection and generation of a resonant frequency in the cavity of a hidden hollow object (the pipeline under investigation);

• search and reception of the generated signal by sensitive elements (piezoelectric sensors) over the search area;

• converting the received signal into a spectrum in real time and saving it in .txt format to a personal computer.

Figure 3.4 shows the appearance of the program panel "Software for monitoring the location of hidden hollow objects by their resonant frequency" ("Generator" tab).

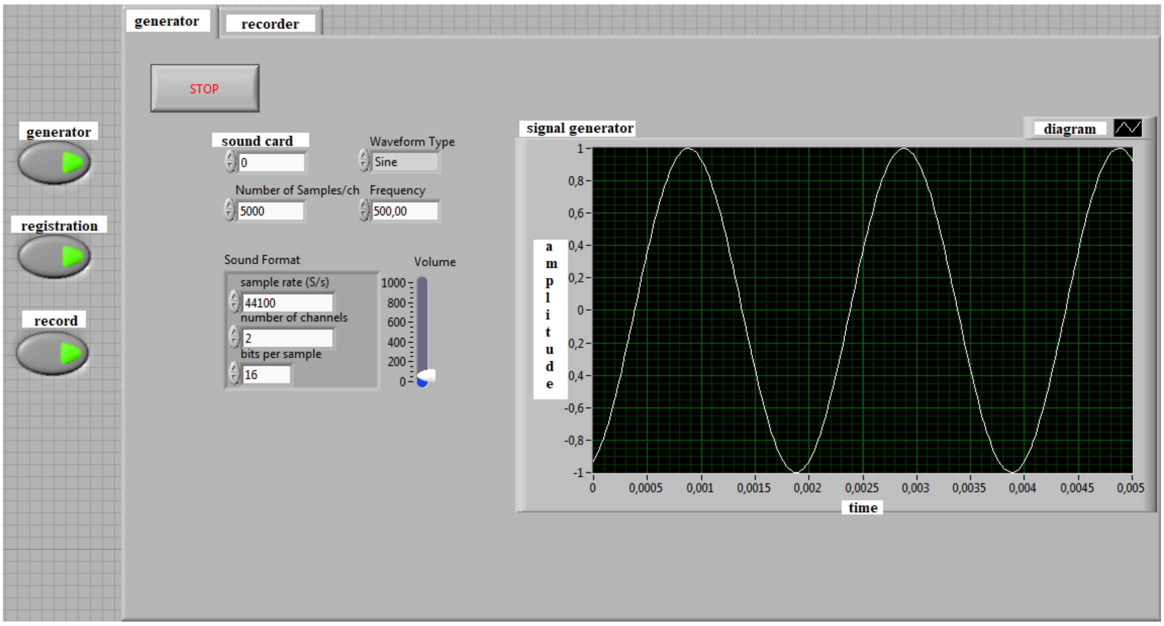

Figure 3.4. Appearance of the Generator tab.

Figure 3.5 shows the appearance of the program panel "Software for monitoring the location of hidden hollow objects by their resonant frequency" ("Registrar" tab).

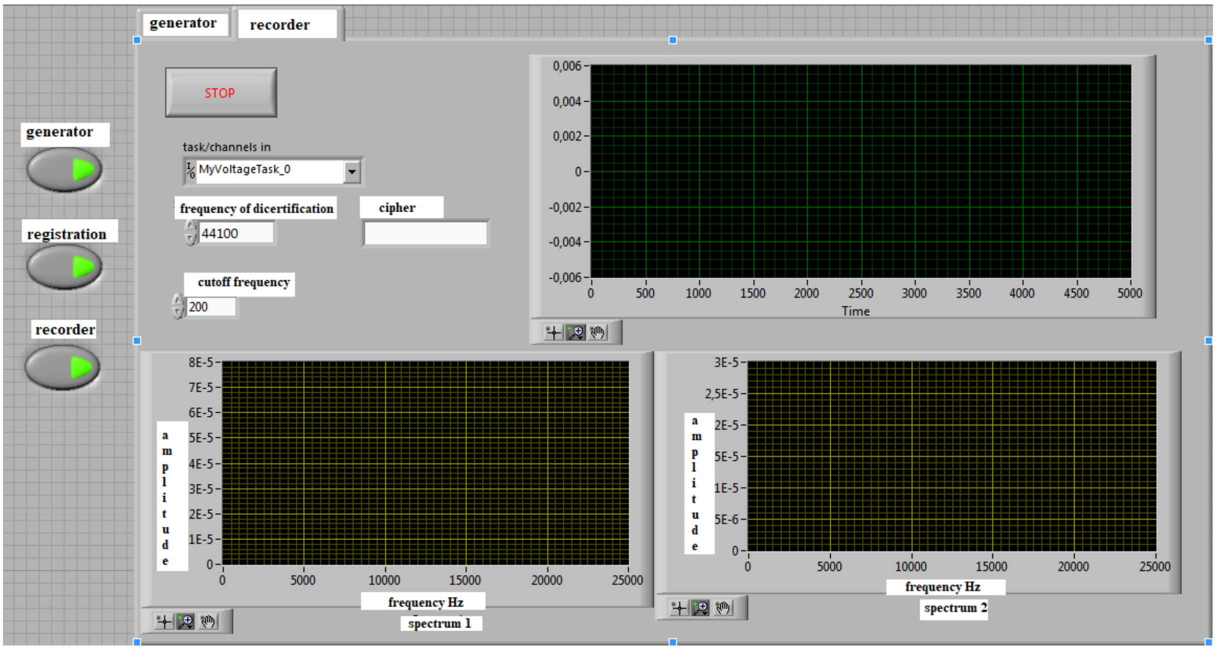

Figure 3.5. Appearance of the tab "Registrar".

4. Experimental studies in the laboratory

Experimental studies for testing the proposed method of monitoring the location of hidden hollow objects of various diameters and materials, and software were carried out in accordance with the following algorithm. The scheme of experimental research is presented in Figure 4.1 [15].

Before the start of the experimental studies, it is imperative to calibrate the information-measuring complex of the experimental installation.

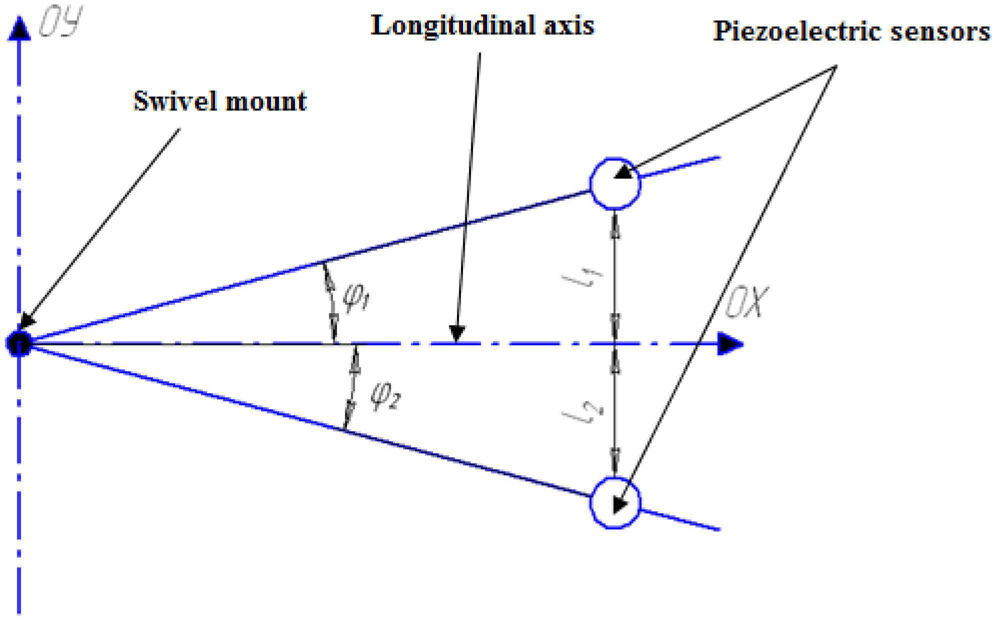

Figure 4.1. The scheme of experimental studies in the laboratory.

Experimental studies were performed in the following sequence:

1. Piezoelectric sensors were installed at equal distances from the longitudinal axis of the investigated pipeline. The initial position of the pipeline is shown in figure 4, which shows that the equality of angles φ1 and φ2 is observed, as well as the equality of distances l1 and l2.
2. A harmonic signal of a sweeping frequency in the range from 300 to 4000 Hz was fed to the acoustic emitter. The resonance frequency of the pipeline was searched by the presence of the maximum amplitudes of the signals received by piezoelectric sensors.
3. An acoustic emitter in the pipeline excited a resonant frequency signal, which was recorded by piezoelectric sensors. The signal from the sensors entered the personal computer, where it was digitized for later comparison. The measurements were carried out at different angles φ1 and φ2 of the deviation of the pipeline from the longitudinal axis (OX) of the installation, at which the distances to the sensors l1 and l2 changed.
4. The amplitudes of the signals received by the two piezoelectric sensors were compared. If the position of the investigated pipeline does not coincide with the OX axis, the difference in amplitudes of the signals received by the sensors should be proportional to the distances l1 and l2.
5. To increase the reliability of the results, at least three measurements should be taken at each position of the investigated pipeline.

The estimation of the error of the information-measuring complex was carried out by a probabilistic-statistical method in accordance with GOST R 8.736-2011, which provides for the determination of the error in the characteristics of the laws of distribution of errors in measuring instruments included in the complex. [1-24].

For the developed complex, the absolute error was $\Delta c = \pm\ 0{,}0139$ V at a confidence probability $P = 0{,}95$ for the average values of the vibration amplitude $\tilde{A} = 0{,}298$ V.

The results obtained with the help of the proposed laboratory installation and software showed the operability and high reliability of the results obtained. Laboratory studies were conducted without taking into account the soil.

5. Conclusion

1) An improved acoustic-resonance method for monitoring the location of hidden hollow objects has been developed and implemented in the form an information-measuring complex consisting of devices for the excitation and reception of forced vibrations.
2) Algorithmic and software-technical support of the management of information-measuring complex and processing of vibroacoustic signals was developed and created in the LabVIEW environment.
3) For testing the proposed method and software, a laboratory installation to control the location of hidden hollow objects made of various materials was created and laboratory tests were conducted.
4) The developed method of monitoring the location of hidden hollow objects using an improved acoustic-resonance method and the method of finite element modeling and information-measuring complex were tested in field tests.

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